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Alternate Forms of the Ambient Air Quality Standard for Photochemical Oxidants

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Review of the primary and secondary ambient air quality standard for photochemical oxidants including an examination of the overall form of the standard as well as a consideration of the appropriateness of the concentration level and averaging time. By using the annual second highest hourly average, an apparently simple means is available for determining compliance. However, analysis shows that there are problems of sufficient importance that alternate forms must be given serious consideration. To ensure compliance with the .08 ppm standard precursor emission levels must be controlled to the point that .08 ppm is never exceeded, which is not a feasible expectation. Thus the current standard is more severe than is apparent from first inspection. A proposed form for assessing oxidant measurements is suggested.

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Staff Summary Paper

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ALTERNATE FORMS OF THE AMBIENT AIR QUALITY STANDARD FOR PHOTOCHEMICAL OXIDANTS

Summary

The present review of the primary and secondary ambient air quality standard for photochemical oxidants includes an examination of the overall form of the standard as well as a consideration of the appropriateness of the concentration level and averaging time. The present form appears to be simple and readily understood. By using the annual second highest hourly average, an apparently simple means is available for determining compliance. However, analysis shows that there are problems of sufficient importance that alternate forms must be given serious consideration.

Because the annual second highest concentration is a single measurement a large measurement error may occur and missing monitoring data may cause the true second highest value to be missed. Further analysis reveals a more fundamental difficulty which has not been as generally recognized. Photochemical oxidant concentrations are subject to random changes in weather and in daily precursor emission levels. Therefore, the average concentration observed in any hour has a random aspect not recognized in the present form. The standard concentration of 0.08 ppm is allowed to be exceeded once annually but never more than once. However, if at a given level of precursor emissions a certain meteorological condition can occur which will lead to oxidant concentrations above the standard once in a year, then there is a definite probability that these same conditions can occur two or more times in a year and, therefore, lead to multiple violations in some years. The only way to assure compliance with the present standard over all years in a given area is to control precursor emission levels to the point that 0.08 ppm is never exceeded, which is not a feasible expectation.

Thus, the current standard is more severe than apparent from first inspection. As discussed in the report its seeming simplicity can lead to inconsistent treatment from one AQCR to the next in deciding both compliance and degree of emission control required. The report recommends that the following form be adopted:

> $\underline{X}$ $\mu g/m^3$ hourly average concentration with expected (average) number of exceedances per year less than or equal to one.

This form represents the least possible departure from the present form while fully taking into account the random statistical nature of factors influencing oxidant concentrations. The recommended form allows for the occasional occurrence in some years when more than one hourly average concentration will be above the standard (the number of such years is set by the choice of the expected number of exceedances per year); it also provides the basis for a consistent approach to decisions on compliance and degree of emission control required. Use of the recommended statistical form requires the use of a substantial portion of the air monitoring data collected in a given year. Thus the statistical estimates that are needed to determine compliance and degree of control are much less subject to measurement error and statistical variation than the annual second highest concentration now used.

Introduction

The present primary and secondary ambient air quality standards for photochemical oxidants are both the same and may be stated as follows:

> 160 µg/cu. meter (0.08 ppm) maximum hourly average concentration not to be exceeded more than once per year.

The review of the oxidant standard now under way will not only include an examination of the appropriateness of the concentration level and averaging time based on our present knowledge of health and welfare effects but will also consider the appropriateness of the overall form (expression) of the standard. The form of the standard could be expressed in many ways, examples of which are: the mean (geometric and arithmetic); expected value; percentile; and some level never to be exceeded. However, since health effects are of primary importance, the form must be compatible with current medical opinion that adverse health effects occur when oxidant levels exceed certain levels for short periods of time. Thus, any form of the standard selected must be directed at minimizing excursions above the designated standard level.

While health and welfare effects are the primary considerations in choosing the most appropriate form of the standard it is also important that the form provide an adequate and clear basis for defining the overall quality of ambient air it is desired to achieve. We, therefore, would want the form

to be such that it: 1. adequately defines what must be measured to determine compliance and measurements which can be made with the needed accuracy; 2. provides clear, unambiguous criteria for determining whether an area is or is not in compliance; and 3. provides a clear, unambiguous definition of the air quality it is desired to achieve to serve as a target for the development and verification of control strategies. This report examines the form of the standard from this point of view and will provide a proper basis for examining the impact of health and welfare effects on the form.

The Present Form of the Oxidant Standard

The current form of the oxidant standard has several advantageous features: 1. It seems to be simple and readily understood. 2. It reflects medical opinion that protection should be provided against the highest levels likely to be encountered in an area when brought under control. 3. It provides in the annual second highest hourly average concentration, a simple, clear indication of the measurement to be made and a clear criterion for determining compliance. However, as the analysis in this section will show, there are problems with the current form which are of sufficient magnitude that alternative forms should be given serious consideration.

Two aspects of the present form of the standard have been criticized by workers in the field and are brought out in the recent petition of the American Petroleum Institute (API) for review and revision by EPA of the oxidant standard. The two concerns stem primarily from the fact that the standard focuses on a single measurement for determining compliance, the annual second highest hourly average concentration. The petition points out that Air Quality Control Regions (AQCR) differ widely in the completeness of their monitoring data over a given year. Because of missing data the probability of capturing the actual second highest concentration can vary from as little as 1% to as high as 99% from one AQCR to the next, depending upon the data retrieval rate. This can result in underestimation of control levels needed on man-made emissions. In some areas a more serious result would be the erroneous judgment that the areas are in compliance with the standard when, in fact, they are not.

The second concern is that the second high is a single measurement and, therefore, bears the full brunt of experimental error. The petition suggests this error may be almost equal in magnitude to the second high itself at the 0.08 ppm level.

The effects of these problems can be reduced by improved monitoring equipment and procedures. They can also be reduced substantially by changing to a form which requires the use of more of the available data to develop a more "robust" statistic, that is, a statistic whose estimates have lower variance or are less subject to random error. Examples might be: the expected (or average) value of the second high, the expected (or average) number of exceedances of the standard, the arithmetic mean of the hourly averages, or the geometric mean.

Further consideration of the form of the present standard, however, shows that it has a more fundamental problem than those discussed in the preceeding paragraphs and one which has not been generally recognized. The present form does not provide a clear, unambiguous definition of the air quality it is desired to achieve, and, therefore, does not provide a clear target for the development of control strategies and their verification. The present standard appears to establish as a target a quality of ambient air over an AQCR such that one hourly average concentration in a given year may exceed 0.08 ppm but never more than one. This is a situation, however, which does not appear to be feasible. There is no level of control of oxidant precursor emissions which will yield a situation in which the standard can be exceeded once in some years but never more than once. Hourly average oxidant concentrations are subject to the random changes in weather and in emission levels. If at a given level of precursor emission control a certain meteorological condition can occur which will lead to oxidant concentrations above the standard once in a year, then there is a finite probability that these same conditions can occur two or more times in a year and, therefore, lead to multiple violations in some years. In this situation the area will comply with the standard some years and be out of compliance in other years.

For example, if under a given level of emissions the probability any given hourly average oxidant concentration will exceed 0.08 ppm is 1 in 8760 (the number of hours in one year), the percentage of years 0.08 ppm would be exceeded a given number of times is shown in Table 1. In 74 years out of 100, the AQCR in question would be in compliance with the standard (either one or zero exceedances), whereas in 26 years out of 100 it would not be. On the average, the AQCR would violate the standard about once every

TABLE 1

VIOLATIONS PER YEAR WHEN STANDARD EXCEEDED AN AVERAGE OF ONCE PER YEAR

NUMBER OF TIMES STANDARD EXCEEDED IN A GIVEN YEAR	PERCENT OF YEARS OCCURRING*	CUMULATIVE PERCENT OCCURRENCE
0	37	37
1	37	74
2	18	92
3	6	98
≥ 4	2	100

*ASSUMES INDEPENDENCE OF HOURLY AVERAGES AND UNIFORM PROBABILITY OVER ALL HOURS

four years. The average number of exceedances per year over a number of years is one in this example (see Note #1). Although the above numbers are not fully applicable to real situations, owing to seasonal and diurnal variations and interdependence of hourly averages, they do illustrate the principle involved.

The only way to assure compliance with the present standard over all years in a given area is to control emission levels to the point that 0.08 ppm is never exceeded. Thus, both from the point of view of compliance and emission control, the present standard is fully equivalent to a standard in which the hourly average concentration 0.08 ppm is never to be exceeded. The present standard requires, therefore, a greater level of control than is apparent from superficial inspection of its form. It seems unlikely that this situation was intended by its formulators. This is the reason for saying the current form seems to be simple and easily understood when its advantages were listed at the beginning of this section. The statement of the standard is straightforward, but its true meaning is understood only when the stochastic or random aspect of oxidant concentrations is appreciated.

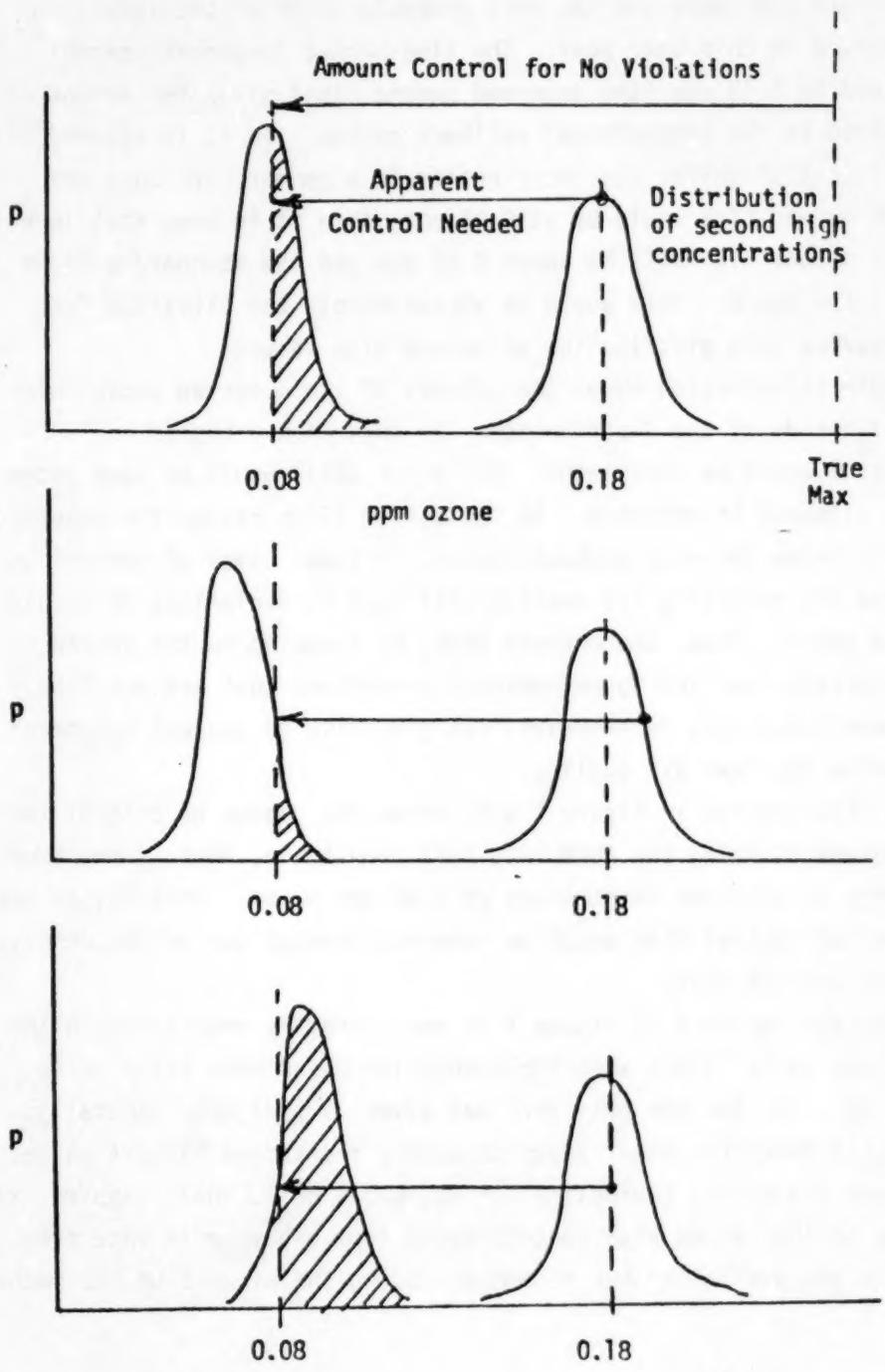
From the preceeding arguments it is clear that the present form has difficulties of a fundamental nature. The end state of overall air quality the standard appears to define is not realizable. In fact, the standard can only be satisfied by an end state in which exceedances never occur.

This latter point has not been fully recognized in establishing guidelines for developing emission control strategies for meeting the standard. For example, if, for the purposes of this discussion, it is assumed the current Part 51 Guidelines for calculating control levels needed for compliance give correct results, the level of overall air quality that would be attained in a given area is such that the area could be in violation (more than one exceedance per year) 50% of the succeeding years. The present practice is to apply Appendix J (or Proportional Rollback) to the second highest hourly average observed in a base year to calculate the degree of control needed to make 0.08 ppm the second highest value. However, because the hourly oxidant values are subject to the random behavior in weather patterns and daily emissions, the observed second highest values will tend to vary from one year to the next. The potential impact of this variation on the calculation of required control levels is shown in Figure 1.

Here it is assumed that the AQCR under consideration has an air quality such that the most probable value of the second highest concentration is 0.18 ppm. The observed second highs in any year around this most probable value

FIGURE 1

EFFECT OF STOCHASTIC BEHAVIOR OF SECOND HIGH CONCENTRATION ON APPARENT AMOUNT OF CONTROL NEEDED AND VIOLATIONS OF STANDARD AT CONTROL LEVEL



note: Shaded area represents fraction of years standard violated when target control level reached

are represented by the probability density function centered about 0.18 ppm. The distribution functions shown are purely hypothetical and only serve to illustrate the stochastic (random) behavior of the annual second high. The top illustration in the figure shows the situation in which data for only one year are available and the most probable value of the second high was observed in this base year. The line marked "apparent control needed" divided by 0.18 ppm (the observed second high) gives the amount of control required by the proportional rollback method. If it is assumed that this level of control shifts the distribution in a manner such that the most probable second high would be at 0.08 ppm, then it is seen that in half the years the second high will be above 0.08 ppm and the standard will be violated half the years. This would be approximately the situation for most AQCR's having this distribution of second high values.

The middle illustration shows the outcome if the observed second high was on the high side of the distribution. In this case a higher level of control would be calculated. But there still would be some years in which the standard is violated. In the bottom illustration the observed second high is below the most probable value. A lower level of control is calculated and the resulting air quality will lead to violations in excess of 50% of the years. Thus, the current form, by focusing on the second high hourly average, has led to recommended procedures that are not likely to lead to compliance and, furthermore, can give rise to unequal treatment of AQCR's having the same air quality.

The top illustration in Figure 1 also shows the degree of control that would be required to bring the AQCR into full compliance, that is the overall air quality in which no exceedances of 0.08 ppm occur. This is, as seen, a higher level of control than would be required through use of the observed second high in any one year.

The situation depicted in Figure 1 is most directly applicable to the situation in the early 1970's when implementation plans were first being formulated. At this time the base year was given as 1971 and, generally, there was little data from other years to modify the second highest value. The most recent guidelines (Guideline Series, OAQPS NO 1.2-047, January 1977) allow the use of the second high concentration from one year if data from other years is not available, but recommends using the highest of the second

high values from three or more years when available. When applied, this procedure tends to favor the case shown in the middle illustration of Figure 1. Even in this case there will tend to be some years in violation and, overall, the effect on different AQCR's will be uneven. Differences will be greatest when AQCR's use different numbers of years to determine the second high. Those which use the smallest numbers of years will tend to have relatively more lenient control requirements.

Other approaches have been suggested which may provide more uniform treatment. R. Larsen has suggested the (average) annual maximum hourly average could be used for calculating the required degree of control. But this measure does not flow as naturally from the standard as does the second high, and there will be some years in which the standard will be violated. Larsen estimates 1 in 8 years will exceed the standard more than once if the annual expected maximum is used as a "design value" to calculate required control. The method, therefore, does not lead to an overall air quality which will fully meet the implicit requirements of the standard.

Alternative Forms of the Oxidant Standard

From the previous discussion it is clearly worthwhile, in reviewing the potential impact of the current understanding of health and welfare effects on the form of the standard, to consider alternatives which avoid the problems inherent in the current form. To provide a clear, unambiguous definition of the air quality which will provide the desired protection of the public health and welfare it will be necessary that the form take into account the stochastic nature of ambient concentrations of oxidant. Forms meeting this requirement will generally define a statistic that is estimated from a significant fraction of the total data base. The measured statistic will be more robust than the second high and, therefore, not as sensitive to missing data and measurement error.

An exception is the nonstochastic form: 0.08 ppm hourly average <u>never</u> to be exceeded. This form provides a well defined end state and a simple test of compliance and is, therefore, acceptable in these respects. However, the maximum possible ozone level in an AQCR is infrequently observed (the maximum value observed in a given year would typically be below this value), and would need to be estimated in some way in order to use currently available methods for calculating degree of control needed.

Table 2 lists several alternate statistical forms each of which unambiguously defines a desired end state of overall air quality. The forms shown were chosen to parallel the present standard in limiting exposure to extremal values of the hourly average oxidant concentration. The first five forms do this directly, the last two indirectly. There should be no difficulty in defining the appropriate statistical forms should medical opinion change concerning the type of protection needed.

The first alternative departs least from the present form. By placing the number of exceedances on an expected or average value basis it avoids the pitfalls of the present standard. Under the statistical form, years in which the 0.08 ppm hourly average was exceeded more than once would not be considered in violation of the standard unless the estimate of the expected number of exceedances was greater than one. Setting the expected exceedances at one is roughly equivalent to the situation depicted in Table 1 (see Note #1). We would, therefore, expect violations of the present form (more than one exceedance per year) to occur on the average of approximately once in four years if the alternate were adopted. Note also from Table 1 that three or more violations in a year would occur an average of approximately only once in every 12 years.

If it is considered that the excursions above 0.08 ppm would be too frequent with the expected number of exceedances set at once per year, the number can be set at a more stringent value such as 1 in 5 years. Thus EPA has two parameters, the concentration level and expected number of exceedanc which can be adjusted to obtain whatever level of protection is needed.

At the present time this general form is recommended over the others in the table because it represents the least departure from the present form, is easy to understand, and the expected number of exceedances can be readily estimated from the distribution of hourly averages over one or more years (see Note #2).

An example of how health considerations enter into the form of the standard is seen in the following variation of the recommended form: 0.08 ppm daily maximum hourly average with expected exceedances per year less than or equal to one. This form would be preferred if medical opinion shifted from the current emphasis on hourly average concentrations to concern about maximum daily hourly average concentrations.

TABLE 2

ALTERNATE STATISTICAL FORMS OF OXIDANT STANDARD

- 0.08 ppm HOURLY AVERAGE WITH EXPECTED NUMBER OF EXCEEDANCES PER YEAR LESS THAN OR EQUAL TO ONE.
- 0.08 ppm HOURLY AVERAGE WITH 90% PROBABILITY (CONFIDENCE) THAT THIS CONCENTRATION WILL NOT BE EXCEEDED IN ONE YEAR.
- 0.08 ppm HOURLY AVERAGE NOT TO BE EXCEEDED ON THE AVERAGE BY MORE THAN 0.01% OF THE HOURS IN ONE YEAR.
- 0.08 ppm ANNUAL EXPECTED MAXIMUM HOURLY AVERAGE.
- 0.08 ppm ANNUAL EXPECTED SECOND HIGHEST HOURLY AVERAGE
- 0.0125 ppm ANNUAL AVERAGE.
- 0.0100 ppm ANNUAL GEOMETRIC MEAN.

The second form in Table 2 also has two adjustable parameters and has the desirable feature of directly displaying the level of confidence that the given concentration level will not be exceeded in a given year. However, the confidence level is not readily deduced from ambient air data. At the present time, it would be necessary to use existing equations developed from extreme value and order statistics which assume no interdependence of the hourly averages. Since these assumptions are not correct for hourly average oxidant concentrations the use of this form, or any form requiring these assumptions, is not recommended at the present time. If independence of hourly averages is assumed, a confidence level of about 37% would provide the same air quality as the first alternate form (see Note #3).

The third form is essentially equivalent to the first but refers directly to the distribution of hourly averages. Notice that in order to avoid the problem of the present form it is necessary to talk about average (or expected) percentage of exceedances. This form is considered less desirable than the first alternate because using a percentage figure forces the use of a very small number, such as the 0.01% in the illustration. There will be less intuitive grasp of the effect of this number of years (the first form). The third and the first forms, as stated in the table, give roughly equivalent protection (see Note #4).

The next two forms each involve a single parameter and thus provide less flexibility than the preceeding forms. As in the case of the second form in the table, they also require the assumption of independence of hourly average concentrations if their values are to be estimated from hourly average ambient air data. The use of an expected or average value results in two distinct air quality end states for these two forms. Based on the discussion in the last section, an AQCR meeting the expected maximum value standard would (assuming independence of hourly averages) violate the present standard an average of 1 in 8 years, while an AQCR meeting the expected second high form would violate the present standard an average of every other year. If the two forms were based on observed maximum or second high values in a given year, the only way either standard could be met consistently year after year would be to achieve an air quality where 0.08 ppm would never be exceeded. This is, of course, the problem with the present standard. In fact, the form 0.08 ppm not to be exceeded by the second highest hourly average in a given year is equivalent to the present

form of the standard.

The final two forms are included to bring attention to the suggestion which has been made occasionally that mean values be used in the oxidant standard in place of extremal values because the former use all the available hourly average data. They are, therefore, much more robust than forms based on extremal values. The presumption is that there exists a correlation between the extremal values and mean values of hourly averages. Supporting data has been advanced to show this to be the case. While good correlations may exist, it would be preferable that the standard reflect the type of protection desired from health and welfare effects. Present medical opinion is that protection should be directed against the excursions in oxidant concentrations rather than at maintaining average levels below some value. Thus the standard should be based on minimizing excursions of the highest ozone concentrations above certain levels. The use of standards based on extremal values would not prevent the use of correlations between average values and extremal values as a means of developing control strategies or confirming compliance with a standard based on extremal values.

Application of Statistical Forms

An understanding of how alternate statistical forms such as the first form in Table 1 might be used in practice can be obtained from examining three potential problems with their use which have been suggested. The first is that year to year variations in weather and emission levels will make it difficult to obtain a stable estimate of the statistic. This difficulty applies to any statistic whose yearly value must be estimated. The second highest oxidant value observed in a given year is, in fact, more subject to this source of variance than the alternate statistical measures given in Table 2. For example, even if general weather patterns and emission levels did not shift from year to year, the observed second high would change from year to year due to fluctuations in weather and emissions within the year to year patterns. There would be an additional source of variation arising from lack of a complete data set and the effect of random experimental error on a single observation.

In contrast, if the first form in Table 2 were adopted, the overall air quality for a given AQCR could be characterized by that hourly average concentration level for which the expected number of exceedances was one. It would not be correct to estimate this statistic by finding the second highest oxidant value for that year. Ambient air data would be plotted on a suitable probability paper and a "best line" fitted to the data (see Note #2). The concentration above which 1/8760 of the data for one year lie is read from the line. The expected exceedance of this concentration is once per year. The concentration corresponding to an expected exceedance of one determined by the above procedure would be expected to show relatively small changes from year to year unless there were significant shifts in overall weather and emission patterns.

The present guidelines use year to year data to define a highest second high for a period of several years. This highest second high is also subject to statistical variance as well as trends over time in weather and emission levels. It would be possible to apply this same procedure to the forms in Table 2. For example, the highest concentration corresponding to an expected exceedance of 1 could be determined from such concentrations for several consecutive years. In reducing the effects of weather and emissions variations within any given year by using more of the available data, the estimated oxidant concentration (expressed in any of the forms in Table 2) would be more reliable and statistically valid because within year variations would be adjusted out. Subsequently, longer-term (year to year) changes in weather and emissions levels also could be separated out of the statistic. The improved statistical forms would therefore allow more accurate tracking of progress in improving air quality.

The second potential problem suggested is that the statistical forms in Table 2 do not provide a positive indicator that an AQCR is out of compliance. This consideration is only potentially applicable to situations in which an AQCR is close to compliance since the statistical forms would easily detect regions significantly out of compliance. Before considering the statistical forms it will be worthwhile to examine the limitations of the trigger provided by the second high concentration. First, the absence of an incomplete data base and experimental error may cause the second high value to indicate compliance when an AQCR is not in compliance. Second, experimental error can also lead to a false indication that the AQCR is in compliance. These problems are reduced with the more robust measures provided by the statistical forms.

Probably more important is the year to year variation in the second igh due to "within year" and "year to year" variations in weather and missions. As discussed in earlier sections, even after emission levels ave been brought to the levels indicated necessary by the second high alue in a base year or over several years, the AQCR will continue to iolate the standard in some years. If further control action is initiated fter each violation (two exceedances in a year), violations will continue o occur after each new control action until finally a level of control is eached in which the 0.08 ppm level is never exceeded. This would be overkill n terms of the air quality which was desired but would be the inevitable onsequence of triggering control action every time the 0.08 ppm was exceeded wice in one year.

In actual practice this is not likely to happen. If the control levels hich have been calculated from the base year(s) have been reached and a iven year is mildly in violation (say three exceedances), control officials ecognizing the variability of oxidant concentrations likely will wait to iew the number of violations occurring next year or over several years efore requiring further control. If these years also show violations hey would probably impose further controls. If violations occurred rela- ively infrequently in succeeding years the officials would probably be isinclined to act further since a substantial amount of additional control ight be required to totally eliminate violations. Thus, the positive rigger provided by the present form would probably not be fully acted on y knowledgeable control officials. Such discretion on the part of control fficials would not be required with the new form of the standard which would orrectly allow for occasional excursion above the standard.

With regard to the alternative statistical forms, it is possible to make these into as positive triggers as desired. The statistic in each of these forms can be estimated solely from the hourly average data within a given year using the approaches discussed in preceeding paragraphs. If the estimate indicates a violation, that year could be established as a new base year and further controls imposed.

However, even though these estimates are less subject to variation than the observed second high it would still be unwise to use the yearly estimates of these statistics alone as positive triggers. Since the yearly

estimates are only estimates of the real statistic corresponding to the overall air quality for a given level of control, it would be better to establish confidence intervals around these estimates. If a predetermined confidence level is exceeded, further control action could be taken. These procedures would only be needed when the region was close to compliance. At this point, each year of additional data would build increased confidence in the estimate of the compliance statistic and provide a more reliable test of departure from compliance. There is, therefore, no inherent problem with the alternate statistical forms as triggering mechanisms for control action.

The third potential problem area is concerned with how to handle an AQCR with multiple sampling sites. The most stringent method would be to pool all hourly averages from all sites in determining compliance by whatever form chosen. In this case an area with several monitors experiencing an oxidant episode spread relatively uniform over the region would almost certainly be in violation. Since it is the same episode over the area this procedure seems rather strict. In the case of the third, fourth, and fifth forms in Table 2 there would be no convenient way to apply this procedure. With these forms, data from the different monitoring sites would in effect be simply averaged.

The second alternate would be to pool all the data from all sites in determining the probability distribution but calculate the statistics on the basis of 8760 observations (the hours in one year). This would put all the forms in the table on the same footing. But it would also dilute the effect of the sites experiencing the highest ozone levels during an episode.

A third alternate would be to apply the standard to each site separately. In this way if the data from any one site in the area is in violation the whole AQCR would be considered in violation. This alternate is intermediate in effect between the two above methods. It appears to combine the positive features of each and, therefore, seems the most reasonable. This alternate is recommended for use with the present standard in the most recent air quality standards guideline. (Guidelines for the Interpretation of Air Quality Standards, EPA-OAQPS-MDAD, February, 1977).

Other concerns with statistical forms which have been expressed are that they lack the simplicity and directness of the present form and, therefore, may not be as readily understood by the public and may present problems in legal proceedings. However, it is clear that the form of the present standard is flawed. If the present standard is applied as stated, an AQCR will only attain full compliance when conditions are such that the standard concentration will never be exceeded. This, as was shown, is a direct consequence of the variable or random aspect of hourly average oxidant concentrations. This stochastic feature of oxidant concentrations can only be taken into account by statistical forms such as those shown in Table 2. These forms are also based on more robust statistics than the second high and provide clear, unambiguous targets for compliance and the development and verification of control strategies.

Notes

1. Probability theory shows that if the probability that a certain event will occur in a given trial is p then the probability, Pm, that the event will occur m times in n repeated independent trials is:

$$P_m = \frac{n!}{m!(n-m)!} p^m (1-p)^{n-m}.$$

This equation is known as the binomial distribution. If it is assumed that p(C) is the probability that the average concentration for <u>any</u> hour of the year is greater than or equal the hourly average concentration C (assumption of independence of hours), the probabilities of 0, 1, 2, 3 exceedances of a given concentration in the 8760 hour in a year can be calculated.

For example:

For no exceedances per year:

$$P_0 = \frac{8760}{0!\ 8760!} \left(\frac{1}{8760}\right)^0 \left(1 - \frac{1}{8760}\right)^{8760}$$

$$= \left(1 - \frac{1}{8760}\right)^{8760} = 0.3679.$$

For one exceedance per year:

$$P_1 = \frac{8760!}{1!\ (8760 - 1)!} \left(\frac{1}{8760}\right)\left(1 - \frac{1}{8760}\right)^{8759}$$

$$= \left(1 - \frac{1}{8760}\right)^{8759} = 0.3679.$$

For two exceedances per year:

$$P_2 = \frac{8760!}{2!\,(8760-2)!}\left(\frac{1}{8760}\right)^2\left(1 - \frac{1}{8760}\right)^{8758}$$

$$= \frac{8759}{2 \times 8760}\left(1 - \frac{1}{8760}\right)^{8758} = 0.1840.$$

The expected or average number of exceedances per year is obtained by summing each number of exceedances per year weighted by its probability of occurance. Referring to Table 1,

Expected exceedances per year = $0.37 \times 0 + 0.37 \times 1 + 0.18 \times 2$

$+ 0.06 \times 3 + 0.02 \times 4 + \text{etc.}$

$= 1.$

Thus the concentration which corresponds to p(C) = 1/8760 is also the concentration with an expected exceedances/year of one.

2. The cummulative distribution of hourly averages over one or more years is defined as a function f(C) where f(C) is the fraction of hourly averages which exceeds the concentration C. This function can be estimated from a collection of one or more years of hourly average concentration data by standard plotting techniques.
If the standard concentration level is 0.08 ppm then the relative frequency f(0.08) multiplied by 8760 is the average or expected number of exceedances per year of the standard concentration. This follows directly from the definition of f(C). This frequency, f(C), is read from the "best fit" line drawn through a plot of hourly average concentration vs. frequency data.

Another useful statistic is the concentration which corresponds to exceedances/year of one. In this case the concentration corresponding to f(C) = 1/8760 is read from the best fit line.

Recent studies suggest that the log normal distribution function does not give a good fit to the distribution of hourly average oxidant concentrations, but the Weibull distribution does. In any case, if a statistical form of the standard is adopted, detailed guidance will need to be given on how to treat the air monitoring data to obtain the needed statistics.

3. The probability that a given concentration level will not be exceeded in a given year corresponds to P_0 of the binomial distribution given under Note 1. As shown, for p(C) = 1/8760 the expected exceedances/year is one (corresponding to the first alternate form of the standard in Table 1), and for p(C) = 1/8760, P_0 = 0.37 (corresponding to the second form of the standard in Table 1).

   Note that calculation of P_0 assumes independence of hourly average concentrations. At the present time there are no formulas for exactly calculating P_0 for the nonindependence case.

4. By the definitions in Note #2, 100 x f(C) is the per cent frequency to be used in the third alternate form. f(C) = 1/8760 for the concentration with an expected exceedances/year of one, and, therefore, 1/8760 = 0.0114% = approx. 0.01%.